Mirror Tech Days 2006

BAUER

Integration of Full-Spectrum Metrology and Polishing for Rapid Production of Large Aspheres

Paul Glenn

September 18, 2006

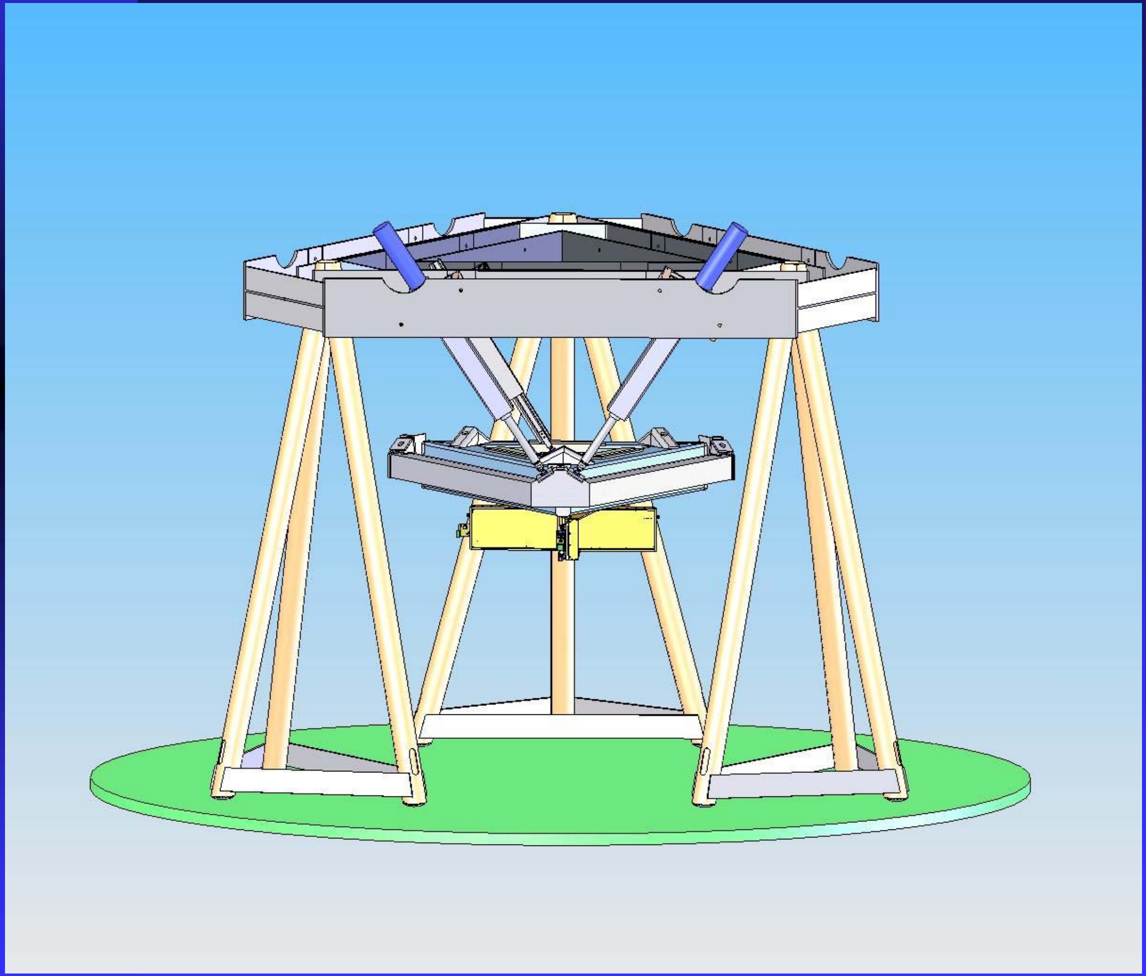
Topics

BAUER

- Integrated, in situ approach to metrology and polishing
  - Hexapod system
- Metrology
  - Full aperture (low frequency)
    - Overview
    - Demonstration measurements
  - Mid frequency
    - Overview
    - Demonstration measurements
  - Micro-roughness (high frequency)
- Polishing
- Machine status and schedule

Integrated, in situ approach

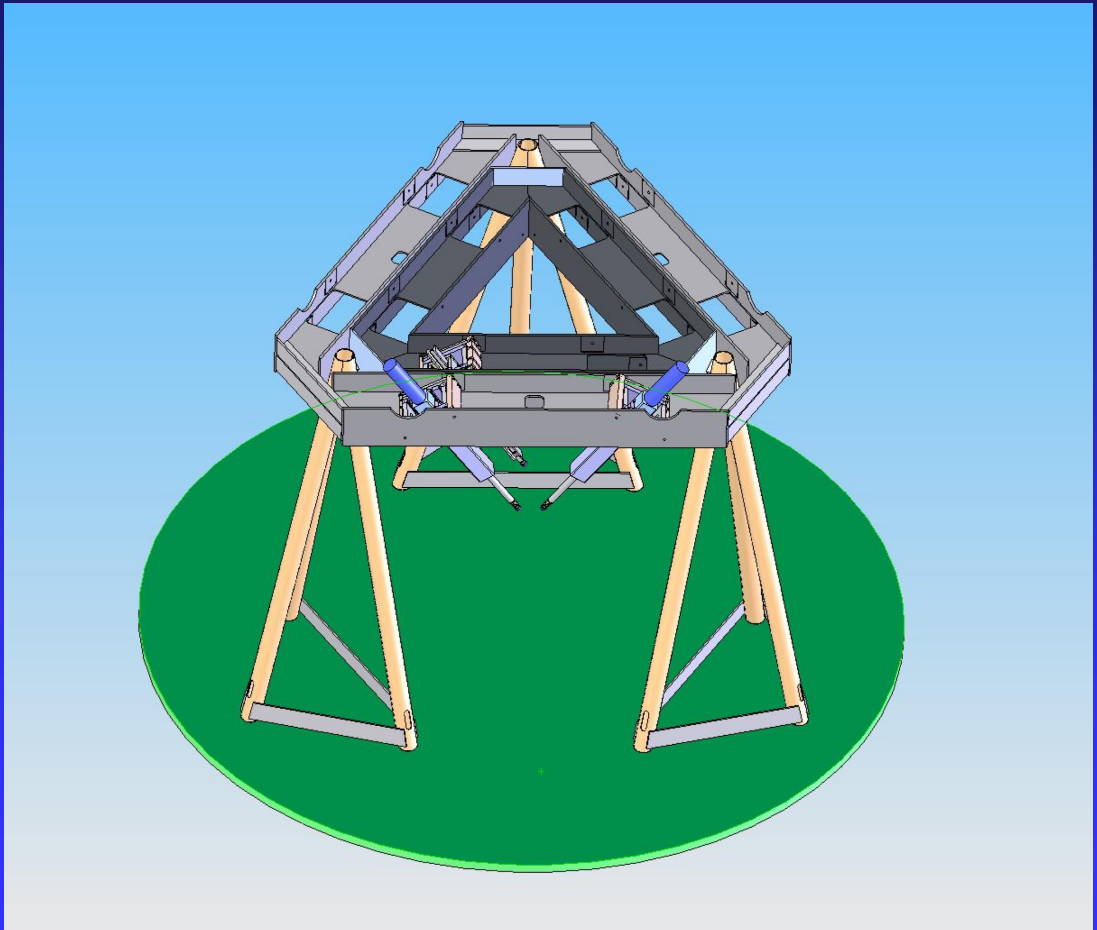
BAUER



- A hexapod structure moves a “platter” in all degrees of freedom over the substrate
- The platter integrates all metrology and polishing functions

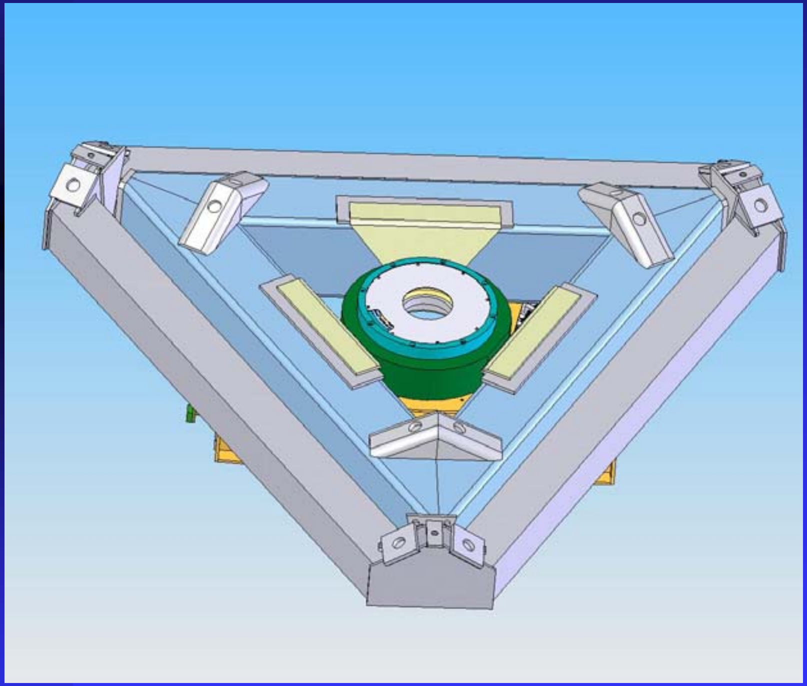
Upper frames for actuation and encoding

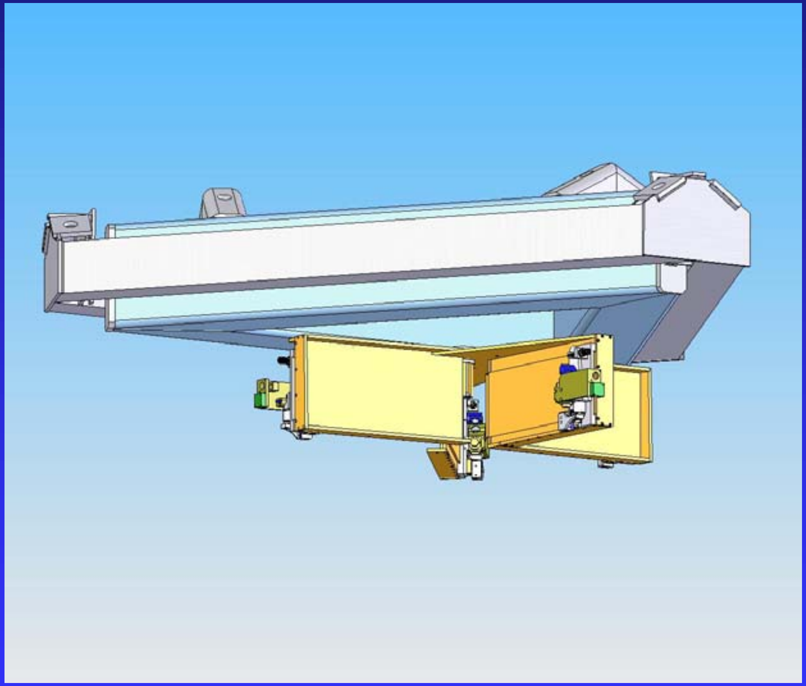
BAUER



Lower ("platter") frames for actuation and encoding

BAUER





Three types of metrology

BAUER

- Full aperture (low frequency)
  - "4 point" optical profilometer
- Mid frequency
  - Curvature-based optical profilometer
- Micro-roughness (high frequency)
  - Total Integrated Scatter (TIS)

“4 point” profilometry (full aperture figure msmnts)

BAUER

- Limitations of interferometry, profilometry
- Three basic principles of 4-point operation
- Summary of advantages
- Demonstration measurements
- Performance predictions

The three basic principles of 4-point profilometry…

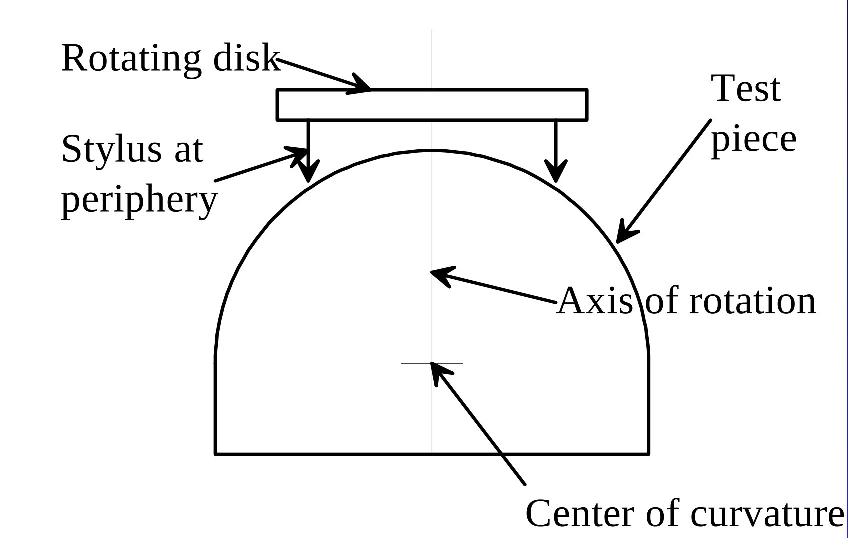
BAUER

- If a rotating platter axis intersects the optic center of curvature, then a probe on the platter nominally sees no change in standoff (convex or concave substrate!)
- If four or more probes are on a platter, then there is *some* linear combination of their readings that
  - (1) is insensitive to all rigid body motions
  - (2) tells *something* about the shape of the test piece

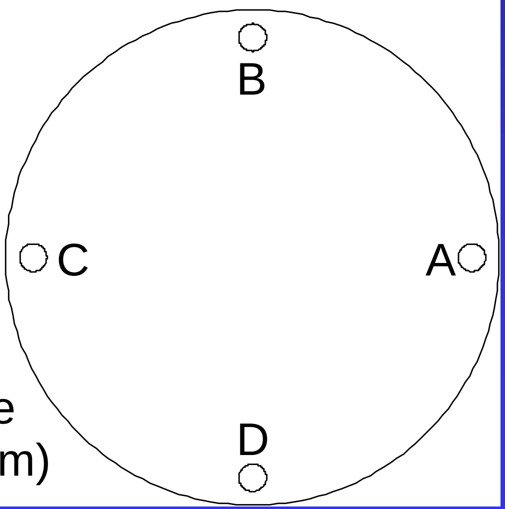
  A continuous measurement of this linear combination as the platter rotates yields a circular "hoop" profile
- If one measures multiple "hoops" around a test piece, with each overlapping at least two others, then it is possible to "stitch" the profiles to obtain the total surface height map.

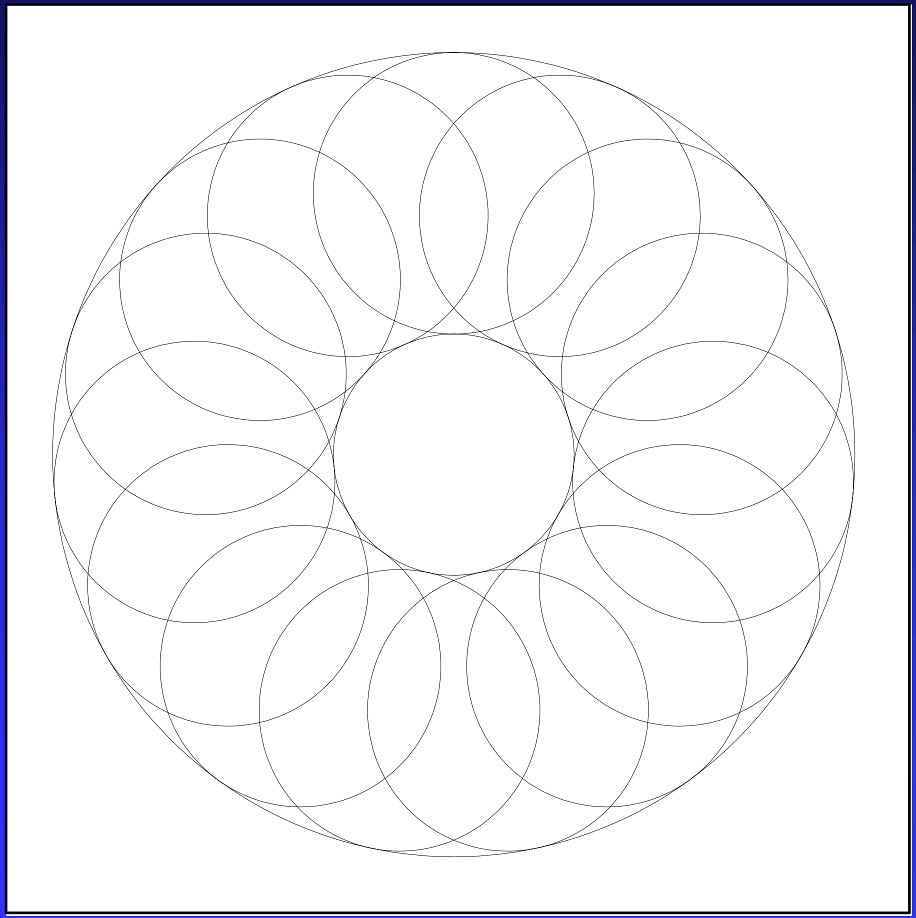
The three principles…

BAUER



Trivial example:
Sum=A-B+C-D
Piston invariant
X-tilt invariant
  (A incr, C decr)
Y-tilt invariant
  (B incr, D decr)
Sees some shape
  (e.g., astigmatism)





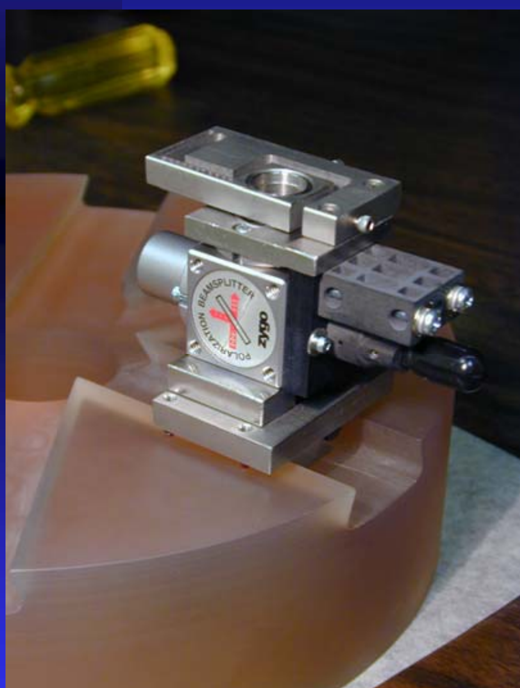
Summary of advantages

BAUER

- Does not work from center of curvature, thus not requiring a massive test tower
- Equally able to test concave and convex optics
- Completely self referencing
- Insensitive to rigid body motions of the test piece during measurements
- (Specially developed laser gauge probes provide absolutely reliable scale factor and mm-class range)
- By replacing the laser gauge probes with coarse probes (touch probes or non-contact alternatives), the instrument can measure optics in their ground state. Thus, one metrology instrument can take an optic from generation through final polish.

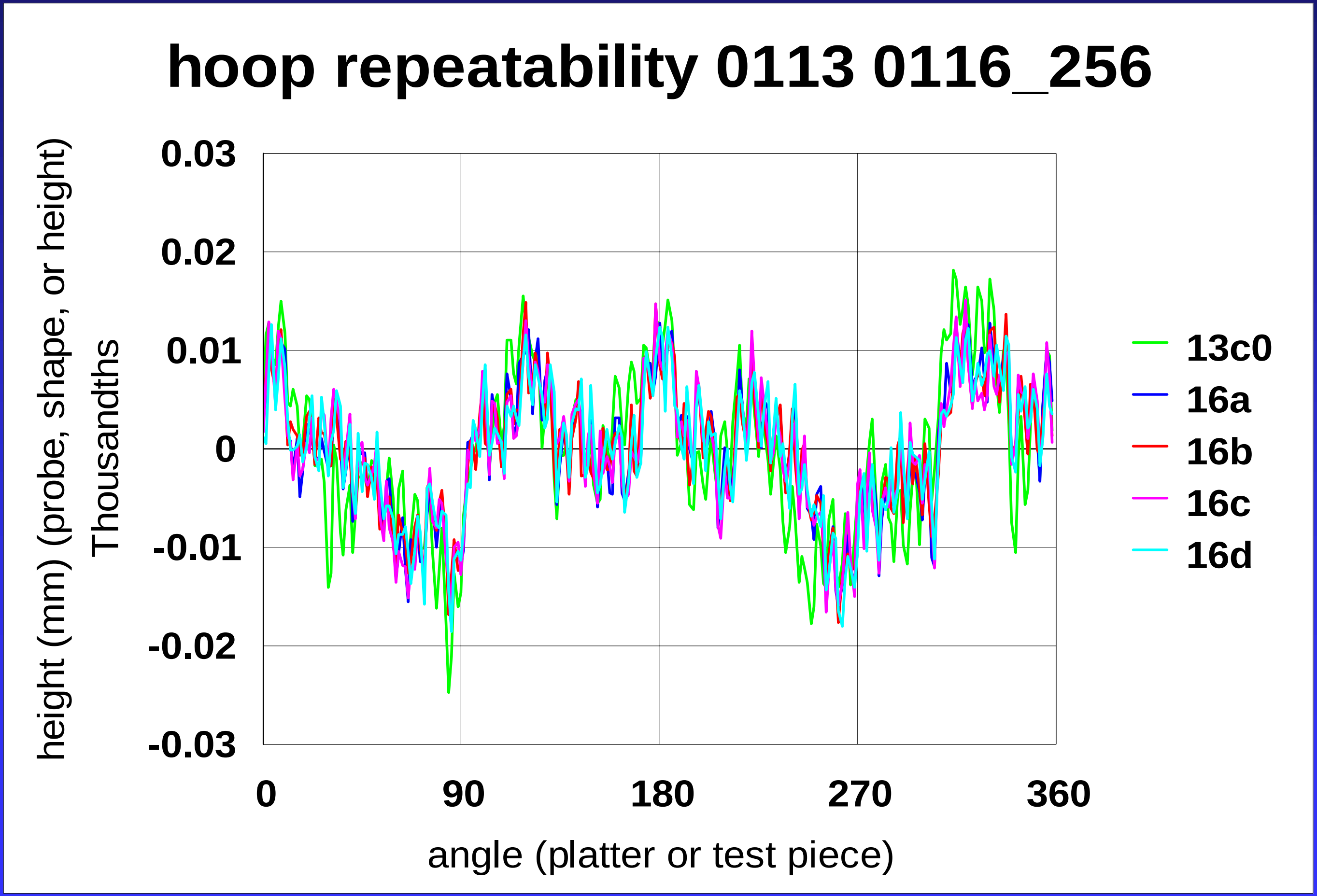
“Platters” – Original, and current for 1.25 m mirrors

BAUER



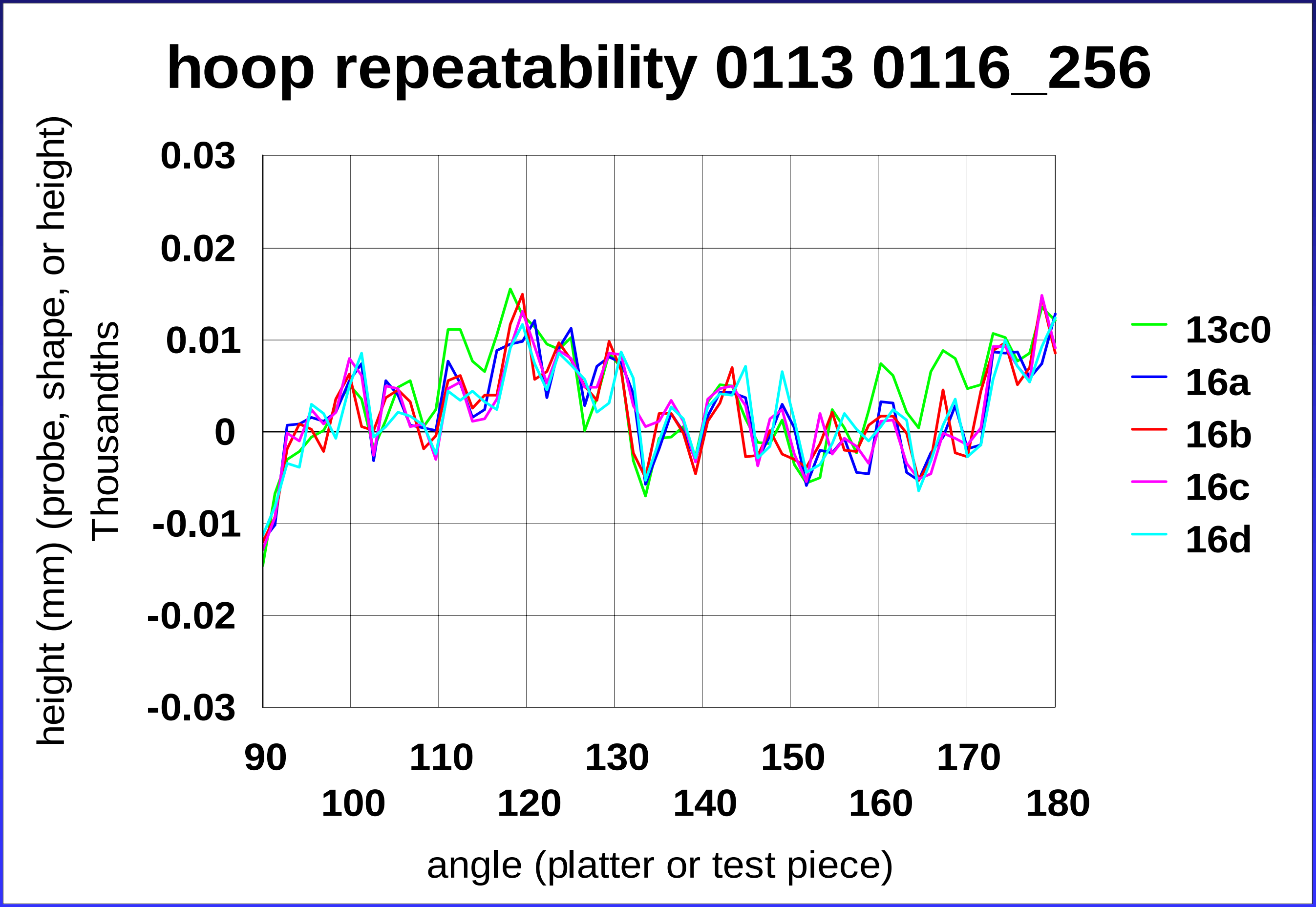
“Hoop” repeatability over full circumference (three days) (each box is 10 nm)

BAUER



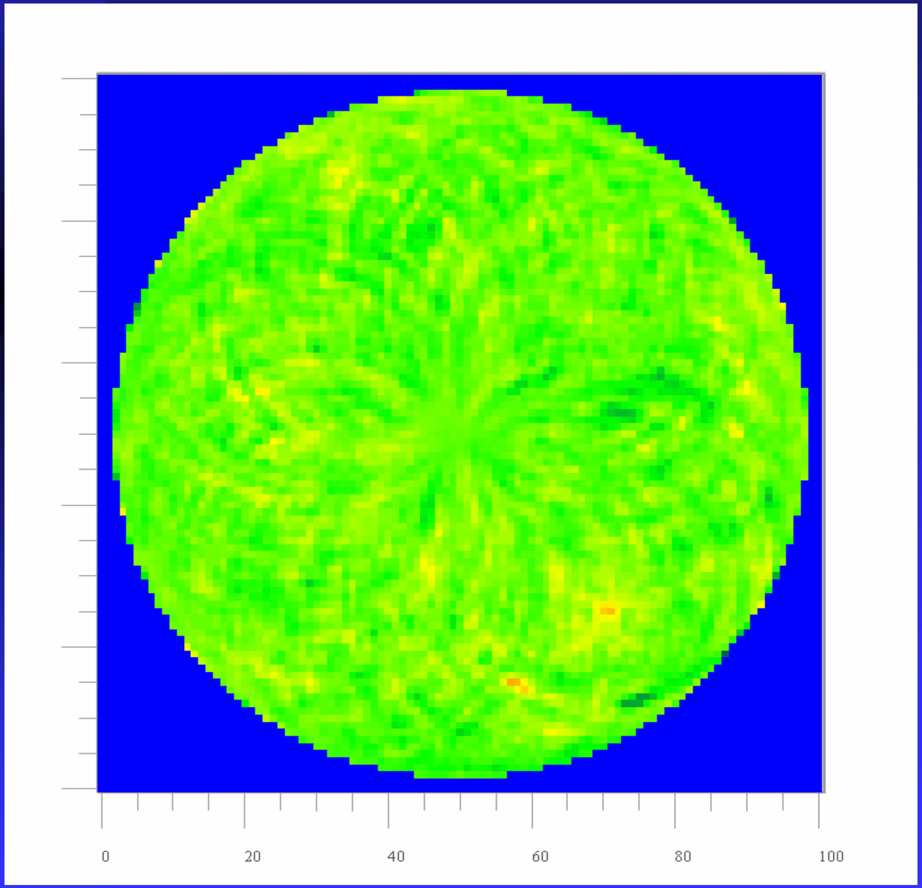
“Hoop” repeatability over just 90 degrees (again, three days) (note 6 mm structure)

BAUER



Full aperture difference between *two independent measurements at different test piece orientations*

BAUER

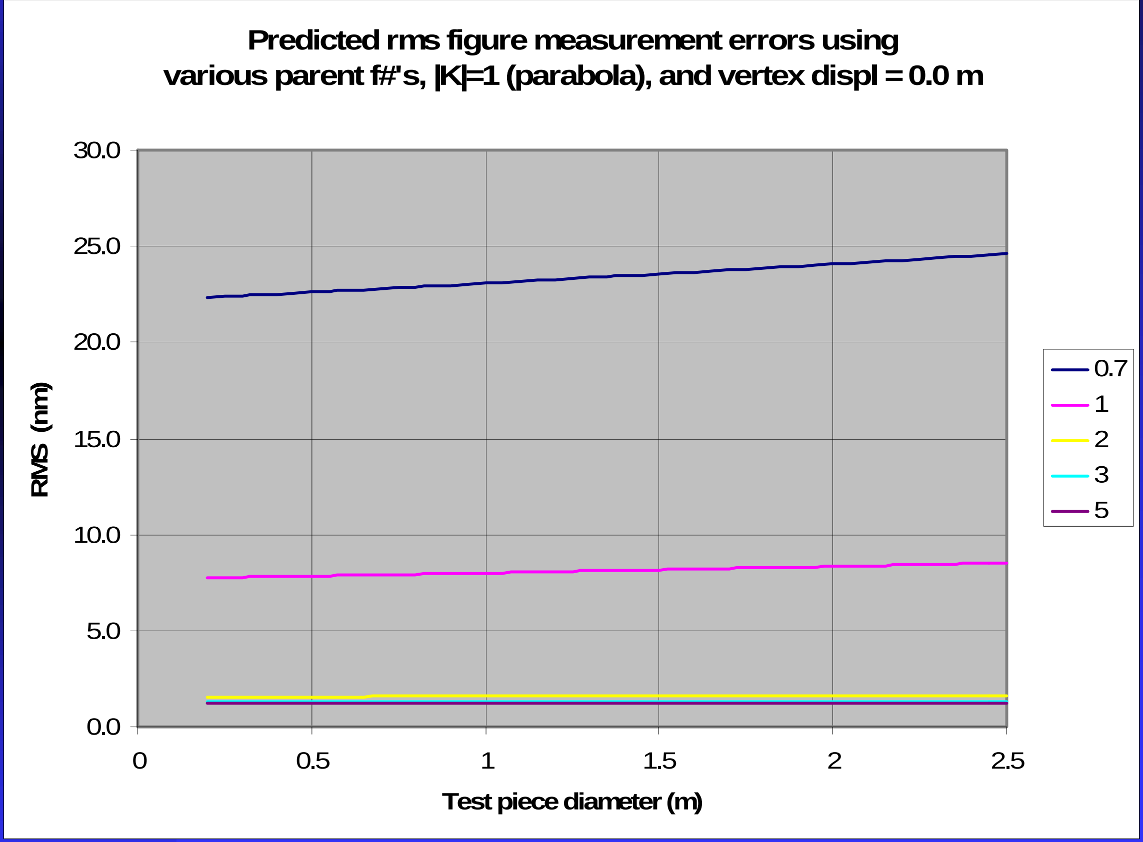


- rms difference = .0025 wave (lambda / 402), or 1.57 nm

- this implies a full aperture error in each measurement of approximately 1.1 nm rms

Predicted ultimate performance

BAUER



- Assumptions:
  - K=1 (parabola)
  - On-axis
- F-numbers examined:
  - F-5 to F-0.7
- Diameters examined:
  - Zero to 2.5 meters
  - (machine under development is 1.25 m)

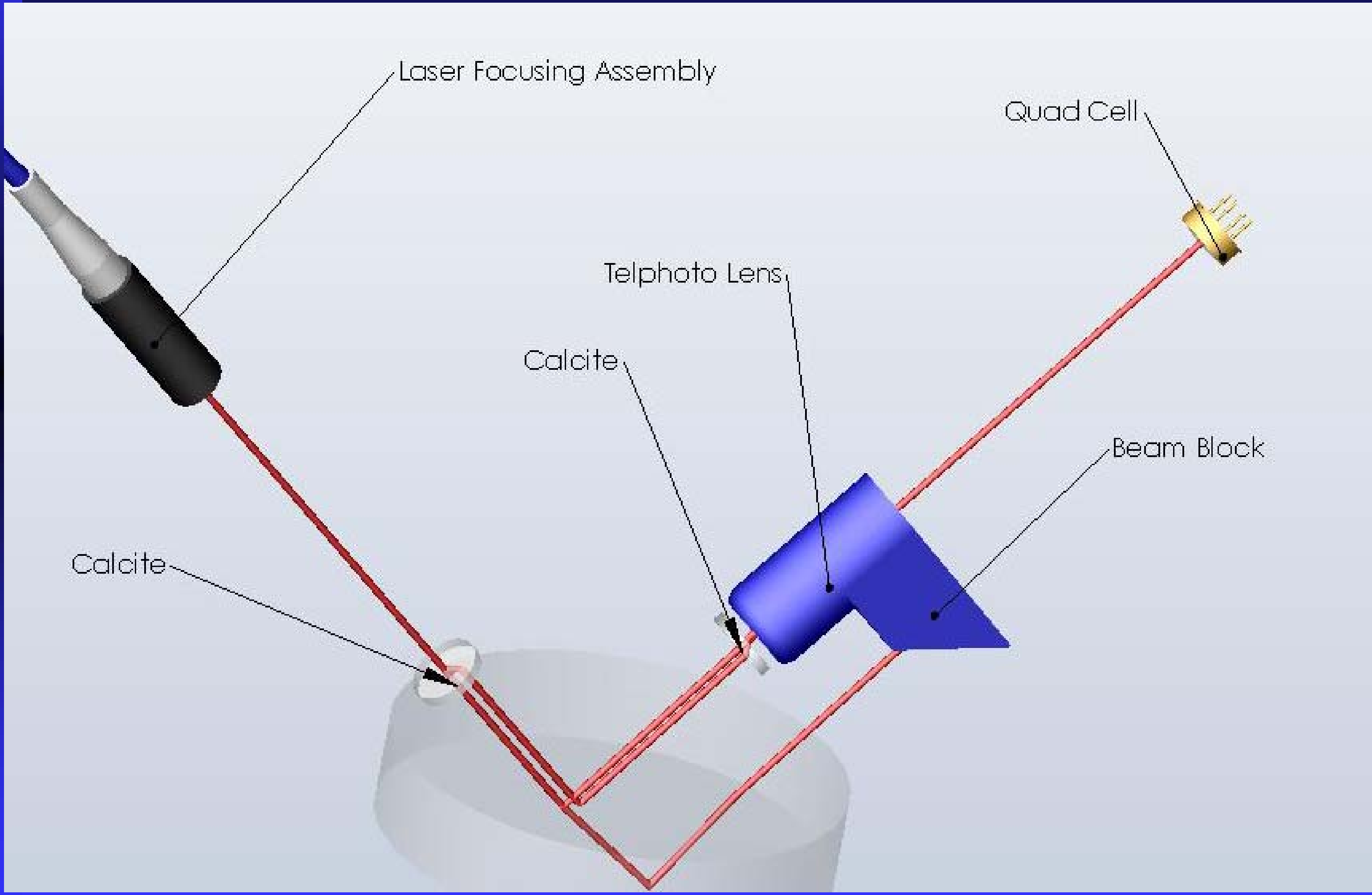
Mid frequency profilometry

BAUER

- Optical measurement of curvature profile, based on Bauer's Model 100 Profilometer
- The mid frequency probe is placed on the same "probe circle" as the 4-point profilometer probes
- Each "hoop" profile is thus independently measured in terms of
  - Low frequency (4-point profilometry)
  - Mid frequency (curvature-based profilometry)
- The profiles are optimally combined in frequency space based on the (frequency-dependent) error spectra of the two measurements

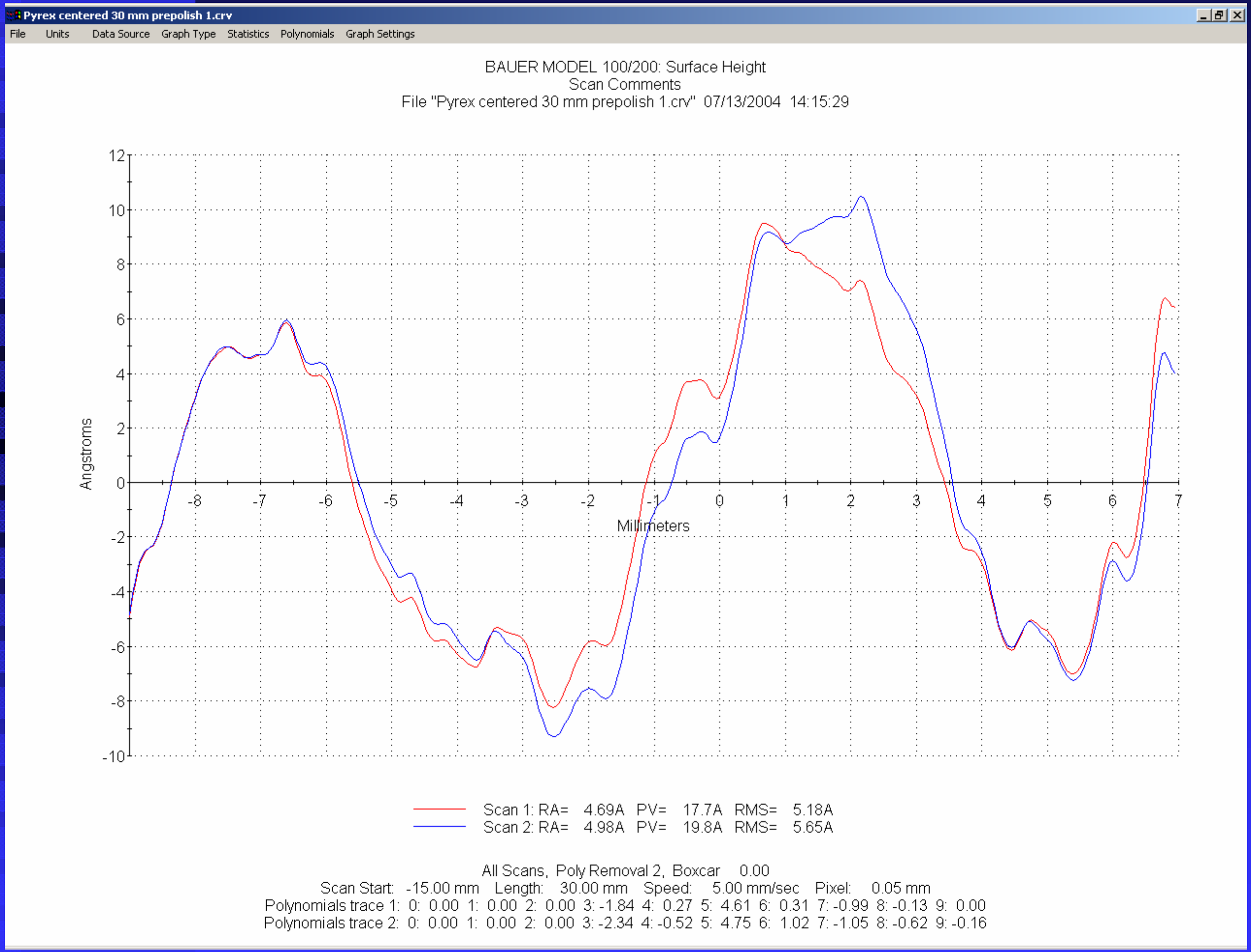
Mid frequency probe

BAUER



Mid frequency data

BAUER



- 15 mm scan is shown
- Each vertical box is 2 Angstroms
- The two scans being compared show rms values of 5.2 and 5.6 Angstroms, with sub-Angstrom rms differences

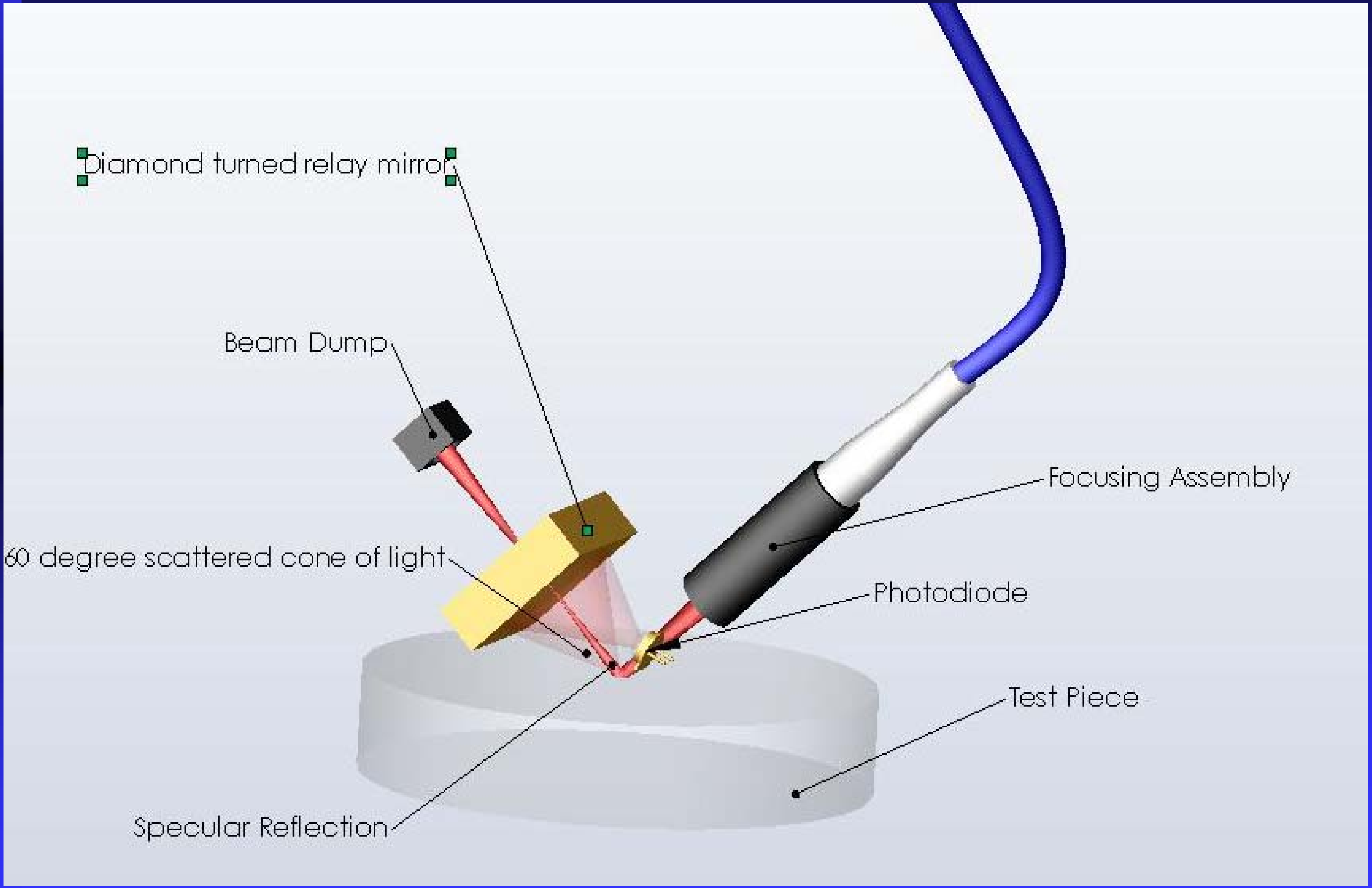
Microroughness

BAUER

- Microroughness is characterized by measuring Total Integrated Scatter (TIS)
- The TIS probe is placed on the same “probe circle” as the 4-point profilometer probes and the mid frequency probe
- TIS is measured, and the band-limited microroughness is calculated and plotted, over the entire surface
- Sensitivity to the 1 Angstrom rms level is expected

TIS probe

BAUER



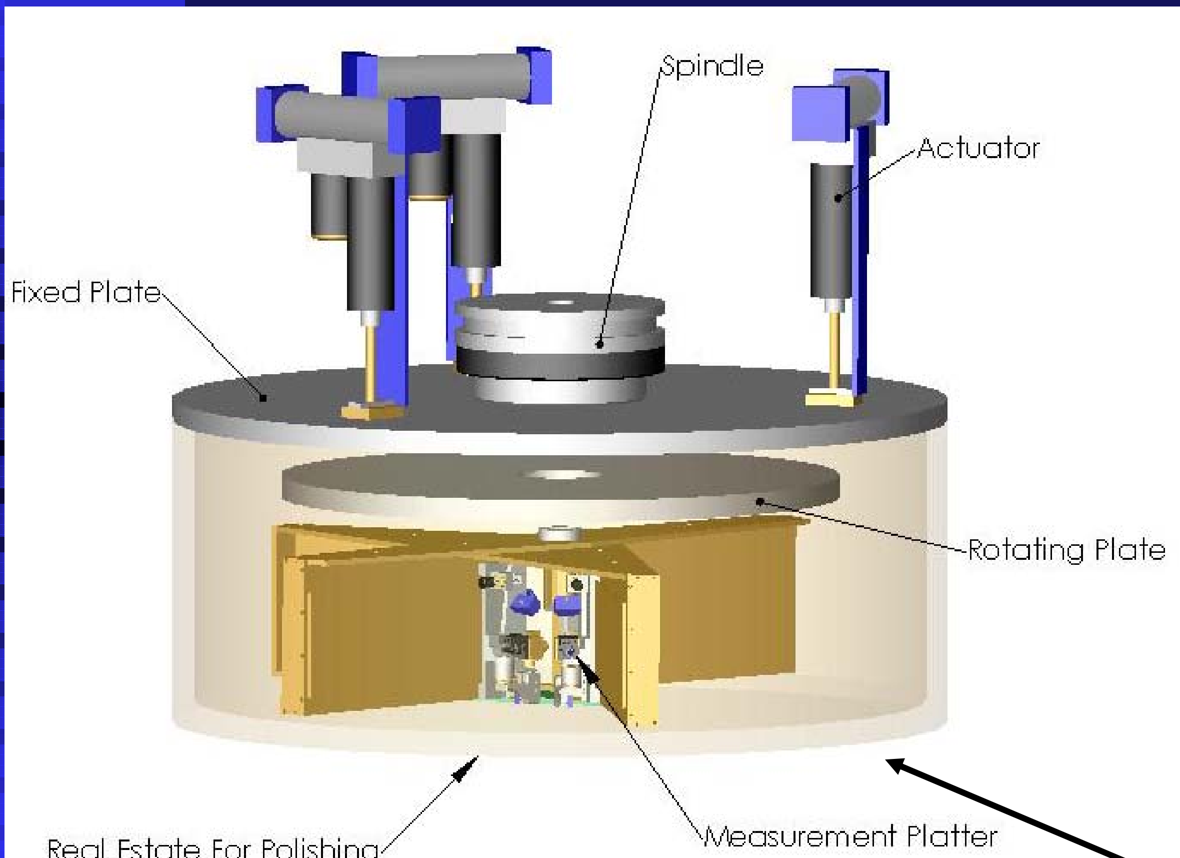
Polishing

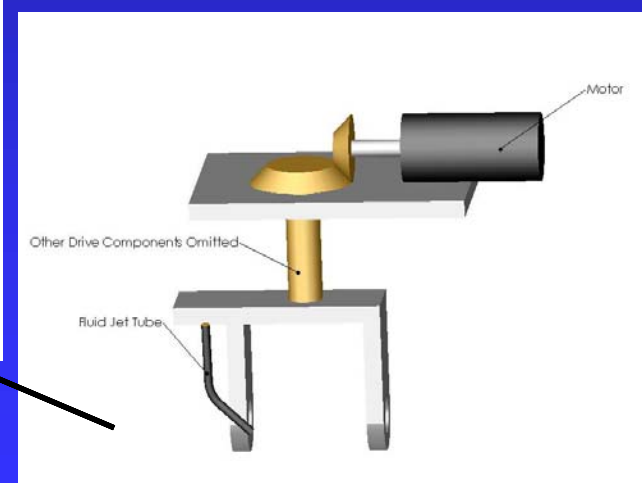
BAUER

- Baseline approach is Fluid Jet Polishing (FJP)
- FJP apparatus is incorporated on a bottom “lid” under the platter, thereby using the *same* hexapod infrastructure as the metrology
  - This is key to our integrated, in situ approach

Polishing

BAUER





Phase I SBIR results for polishing experiments

BAUER

- We used several grit sizes and pump pressures
- We were able to remove hundreds of microns of material with the coarsest grit size and highest pressure
- We found smoothing action to a small fraction of a grit size for a wide range of grit sizes (work in the literature tends to confirm the ability of FJP to polish without degradation of roughness)
- We found excellent preservation of mid frequency figure when polishing for roughness
- Much more polishing work needs to be done at the conclusion of this project, but the prognosis appears good

Status, schedule

BAUER

- We have completed
  - All of the overall design
  - Almost all of the detailed structural design
  - Hexapod calibration algorithms
  - Much analytical and software work on polishing path generation and dwell optimization (still in process, collaborating with another project)
  - Performance predictions
  - Major procurements
- We have begun the machining and assembly

Status, schedule (cont'd)

BAUER

- November '06
  - Complete superstructure (hexapod) fabrication and initial assembly
- December '06
  - Achieve first coordinated motions
  - Integrate the "platter"
- January '07
  - Get first data from the "4-point" profilometer
- March '07
  - Fully operational machine